Feasibility study on environmental protection reform of ship stern tube system based on water lubrication

Yang Cui
WORLD MARITIME UNIVERSITY
Dalian, China

Feasibility Study on Environmental Protection
Reform of Ship Stern Tube System Based on Water Lubrication

By

Cui Yang
W1904166
The People’s Republic of China

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In

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

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Signature:
Date: June 28, 2020

Supervised by: Professor Li Guobin
Professor of Dalian Maritime University
Looking back at the scene of learning over the past year, I have gained a lot. Thank you for the Master's program jointly organized by World Maritime University and Dalian Maritime University. As the thesis is about to be completed, I would like to extend my most heartfelt thanks to the teachers, classmates and family members who have helped me in my study and life for more than a year.

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ABSTRACT

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Replacing lubricants with water has two advantages: on the one hand, it is low-cost, recyclable, safe and reliable; on the other hand, it can avoid pollution caused by lubricant leakage. In this paper, starting from the current situation of oil pollution caused by ships to the ocean and inland rivers, two main methods of ship stern bearing lubrication—oil lubrication and water lubrication are introduced.

In terms of the structure of the two lubrication systems, the water lubrication system is simpler and the oil lubrication system is more complicated. The sealing components of the oil lubrication system are more demanding than the water lubrication system. Not only are there two sets of sealing devices for the front seal and the rear seal (the water lubrication system only needs the front seal).

However, the current water lubrication system still has some shortcomings, this article provides two solutions. One idea is to add forced lubrication equipment on the basis of the existing open lubrication—On the one hand to ensure that the cooling water has sufficient flow, to filter out the sediment, and extend the life of the water-lubricated bearing. On the other, to replace the oil directly with water on the basis of closed lubrication. However, it is necessary to ensure that the temperature of the water is not too high and can achieve the same effect as oil lubrication.

No matter how the lubrication system is changed, the bearing is the most critical link. This article discusses the classification of water lubricating materials and the advantages and disadvantages of various water lubricating materials. It further discussed the friction mechanism of water lubrication, and then provides theoretical
support and material selection for the transformation of marine water lubrication system

**KEY WORDS:** Oil pollution, water lubrication system, composite modification, friction mechanism.
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LIST OF ABBREVIATIONS

CCS--China Classification Society
CLC--International Convention on Civil Liability for Oil Pollution Damage 1969
L/D --Long/Diameter
UHMWPE---Ultra-high molecular weight polyethylene
SCF---Supercritical Fluid
PEEK--Poly-ether-ether-ketone
PTFE---Poly tetra fluoroethylene
CF---Carbon fibre
PV—Pressure and velocity
CHAPTER 1 INTRODUCTION

1.1 Research background and significance

With the development of economy, people pay more and more attention to environment, and the problem of environmental pollution is becoming more and more prominent. It has gradually become one of the common concerns of all countries in the world. With people's increasing awareness of ecology and environmental protection, the defects of lubricating oil in environmental protection are becoming more and more obvious, leading many mechanical designers and manufacturers to look for new modern mechanical equipment with low prices, simple structure, energy saving and environmental protection.

Bearing is very important mechanical component in mechanical equipment. According to the difference of their friction properties, they can be divided into sliding friction bearings and rolling friction bearings. It is understood that about half of the energy in the world is lost through various forms of friction and wear. Among them, various forms of wear are the main causes of mechanical equipment failure, and wear is mainly caused by friction, and the friction loss of sliding bearings accounts for a large part of it. At present, the main research directions of researchers are bearing structure, anti-friction materials and lubricating media, etc., in order to reduce the friction loss of sliding bearings, and improve the working efficiency and service life of sliding bearings. (Xu, 2006)

According to the latest survey of the ship inspection department: Taking the Middle Yangtze River as an example, about 3.2t of mineral oil leaks from large and medium-sized ships that use oil-lubricated ship stern bearings into the waters of navigation every year (Yi, XJ & Wang YQ, 2004), and there are many large and small
ships sailing in the Yangtze River. It is conceivable that the amount of lubricating oil leaking in the water is likely to cause serious water resource pollution and irreversible ecological damage after a few years. Some Western countries with highly developed industries, such as Britain, France, and the United States, have made it clear that in order to protect and clean the water environment on which people live, it is strictly forbidden to use mineral oil lubricated ships to sail in inland rivers. (Huang, 1997) Therefore, countries should promote the application of water-lubricated bearings that are non-polluting to the water environment in modern industry. For example, ships and machinery operating in water use bearings that use water as a lubricant as much as possible. New environmentally friendly bearings with functions such as environmental protection and prolonging the service life of mechanical equipment are used to solve the pollution conditions faced by rivers, lakes and oceans. (Zhang, 2008)

1.2 Research content

Bearings are vital components in the lubrication system. Compared with oil-lubricated bearings, water-lubricated bearings have the following advantages:

(1) Low cost of use. Lubricating oils are mostly mineral oils, which are derived from petroleum refining and processing, and their production and use costs are very high, and water-lubricated bearings are directly lubricated with water. For ships, turbines, pumps and other mechanical equipment used in water, lubrication the media can be taken on-site, basically without processing, so the cost of its use can be almost negligible.

(2) Environmentally friendly and resource-saving. Using mineral oil as a lubricating medium not only consumes a lot of mineral resources, but also pollutes the environment due to the leakage of lubricating oil, destroys the ecosystem, and threatens human health and even survival. If water is used as the lubricating medium, there will be no pollution and the effect of clean lubrication will be achieved.

(3) The structure is simple and easy to maintain. Oil-lubricated bearings require oil
supply devices, lubricating oil filter devices, indicating devices, sealing devices, etc. in use. These devices result in a very complicated structure and cause certain difficulties for maintenance and repair. The structure of the water-lubricated bearing is simpler, and the bearing can be cleaned by the flow of water, so it is easier to maintain.

(4) Good flame retardancy. Mineral oil is flammable and can easily cause vicious accidents under high temperature and open flame. The water is not flammable, and water is also a good extinguishing substance, so it is safer.

(5) The friction coefficient is low and the cooling effect is good. The viscosity of water is very small, less than 1/20 of oil, so its viscosity resistance is small and the coefficient of friction is low. At the same time, the specific heat capacity of water is the largest among common substances, and it is also a commonly used coolant with good cooling effect.

But water-lubricated bearings also have some disadvantages:

(1) The boiling point of water is relatively low, and generally it cannot be used in an environment with a water temperature above 100 degrees Celsius; otherwise, it cannot be used in an environment below the freezing point of water;

(2) Water, especially seawater, has good electrical conductivity and strong rust, which can easily cause electrochemical corrosion of metal materials and aging of polymer materials;

(3) The cavitation pressure of water is high, and cavitation is easy to occur in bearings running at high speed. The cavitation will destroy the stability of the bearing and erode the material.

(4) The viscosity of water is low. Although it can reduce the friction coefficient, it will also lead to a significant reduction in the carrying capacity. Especially in the case of shaft start and stop, impact, etc., the lubricating water film is not enough to completely separate the journal from the bearing so that the water-lubricated bearing is in a mixed lubrication state.
Based on the above characteristics, this paper first discusses the possible pollution and status quo of the environment caused by the oil lubrication system. Then it takes the composite material water lubricated bearing as the research object, explores the water film bearing mechanism and lubricating characteristics, and combines different working conditions, structural parameters and operating environment to analyze the water lubricated bearing. It improves the problems of water-lubricated bearings, their lubrication performance and load-bearing capacity, and explore the feasibility of transforming oil-lubrication systems into water-lubrication systems on a large scale. This is of great significance for protecting the natural environment, saving water resources, promoting industrial development and technological progress, and promoting economic growth.
CHAPTER 2 The status quo and countermeasures of ship oil pollution

2.1 Status of ship oil pollution in offshore and distant sea basins

The occurrence of marine environmental problems is mainly due to the fact that people have damaged the marine environment to varying degrees in the process of development and utilization of the ocean, especially the discharge of pollutants to the ocean. Most of these wastes eventually enter the ocean directly or indirectly. Due to interconnection and spread to the surrounding ocean area, and even the later effects spread to the world, once pollution is formed, long-term treatment is required and the treatment cost is large, and it is difficult to completely remove it.

Among them, the pollution caused by ships accounts for 45% of marine pollution. With the development of the maritime industry, the volume of cargo transportation and oil transportation at sea continues to increase, and various oil pollution accidents may increase. From a probabilistic point of view, there will be an upward trend in the future, sometimes disastrous. Therefore, how to control the oil pollution emissions from operating ships and protect the marine environment is a practical problem we must face. (Wang J X, 2001)

Spilled oil (crude oil, lubricating oil) pollution is extremely damaging to fisheries, especially juvenile fish and roe, thereby destroying fishing grounds. The oil film and oil block will adsorb a large number of fish eggs and juvenile fish in a short time, polluting the catches, fishing nets and breeding equipment, and most likely directly causing the death of fish. (Liao G X, 2012) The production of plankton on which marine animals depend is also declining, leading to a direct reduction in catch. The spilled oil diffuses through ocean transportation, in which the polycyclic aromatic hydrocarbon components such as naphthalene and anthracene and the heavy metal components such as lead and zinc are dissolved and distributed in the seabed sediment and water environment, which greatly reduces the seabed and seawater The quality of
the habitat is not conducive to the survival and reproduction of marine life. (Luo, 2005) (Han, 2003)

Due to the complexity of the marine environment, once an oil spill pollution accident occurs in the operation of the marine shipping industry, in addition to the irreversible damage to the marine ecological environment and the huge cost of restoration measures and cleanup of oil pollution, it will also lead to the closure of the waterway, causing serious damage to the marine aquaculture industry along the coast, and it is difficult for fishermen to go fishing. The nearby seafood restaurants, hotels, craft gift shops, and marine specialty shops are often closed. A series of losses, such as loss of oil pollution, are purely economic losses.

Ocean oil pollution has the following characteristics:

(1) Ship pollutants are highly mobile. Ship operations are not static but sail at sea at all times. Ship pollutants will also move on the sea as the ship sails. Moreover, seawater has mobility, and pollutants from ships entering the ocean will also spread with the flow of seawater, so a ship pollution incident may involve multiple sea areas.
or multiple countries.

(2) Ship pollutants are persistent and harmful. Such pollutants discharged into the sea are difficult to decompose and transfer autonomously, and will slowly accumulate in the ocean. Ship pollutants can damage seawater quality, break the marine ecological balance, affect biological resources, and change the living environment of animals and plants. Pollutants can even accumulate through the food chain and accumulate in marine organisms, thereby affecting human health. When the pollutants exceed the self-purification ability of seawater, it will have a significant impact on its own pollution decomposition function, seriously damaging the marine ecological environment and fishery resources.

(3) It is difficult to deal with ship pollutants. Ship pollutants are mainly oily substances. At the current technical level, these pollutants are difficult and expensive to handle on land. In the vast sea, the pollutants diffuse faster, have a wider range of impact, and consume less emergency response. The length of time and the lack of emergency supplies make handling operations even more difficult.

The ship's stern tube oil leakage is different from the large-area crude oil leakage. It is more difficult to count, and it is difficult for an organization to give accurate data, but the leakage situation occurs every moment.

2.2 Status of ship oil pollution in inland freshwater basins

Take the Yangtze River in China as an example.

There are more than 3,600 navigable rivers in the Yangtze River Basin, accounting for 70% of China's inland waterway mileage, and the various transportation network density indicators are higher than the national average. The density of transportation network is higher than the national average by 50% per 10,000 people. The density of transportation network is more than three times the national average per 100
kilometers. The comprehensive density and economic density are also more than twice the national average, showing the advantages of the Yangtze River shipping network and its status and role in the nation’s inland waterways. (Wu Biao, 2000)

At present, the average flow of ships in the Three Gorges Reservoir Area is about 400,000 ships per year, the daily flow of passengers in the port of the Reservoir Area is about 30,000, the freight volume is 30 million tons per year, and the ship transportation industry employs more than 100,000 people. (Zhang XD, 2004)

According to conservative estimates, ships and ports generate 400,000 tons of garbage, more than 7 million tons of manure, more than 15 million tons of domestic sewage, and more than 1 million tons of oily wastewater in the reservoir area every year. Fuel and cargo oil leakage caused by traffic accidents averages about 150 tons per year. (Wang MN, 2004) Pollution from ships also includes chemicals, exhaust gas, cabin washing water pollution, and ship noise. Most sewage is directly discharged into the Yangtze River without treatment; The transportation volume of oil and chemicals in Gezhouba reached 1 million tons each, and the risk of large-scale oil spill accidents on the water greatly increased.

After the Three Gorges reservoir was built, the water quality of the reservoir area became clear, and the stern tube system of most newly-built ships still used oil lubrication. (Zhou 2004) Under normal circumstances, the stern tube system in the form of oil lubrication has long service life, convenient maintenance and low cost. Although the leakage of lubricating oil cannot be avoided in the system during operation, due to the strong purification function of the Yangtze River water in the past, such leakage during normal use has not yet formed a very intuitive pollution. (Huang Yongchang 1999) However, in recent years, with the development of the Three Gorges Reservoir area’s economy and people’s livelihood, the fish farming and fishing industry in the Reservoir Area has begun to rise, and many abandoned fishing nets have been thrown into the river, often leading to accidents in which propellers are entangled in fishing nets and ropes during ship operation, thus
making the stern shaft seal invalid or damaged, resulting in sudden oil leakage. Compared with the amount of leakage in normal operation, this sudden oil leakage is often a gap of ten times or even a hundred times. Take a 326KW working boat as an example, with two engines and two propellers, under normal working condition, the consumption of lubricating oil (single shaft) of the stern shaft seal is about 8 ~ 10ml / h. ) Consumption can usually reach 1000ml / h, or even more.

At present, most of the lubricating oil used in the ship stern tube system is the waste engine oil replaced by the host, which often contains some heavy metal impurities. Once this sudden oil spill accident cannot be effectively controlled, with the increase of such accidents accumulating over time will inevitably form a new source of pollution in the reservoir area.

According to the CCS investigation and disclosure: According to China ’s current standards for installation and inspection of ship stern shaft seals (JT / T 286-1995, CB / T3419-1992): Rotate the shaft system slightly at the time. Generally, the end seal device should not leak oil during the test, but it is allowed to be used when the oil drop per minute does not exceed 2 to 3 drops. " If the average leakage (normal consumption value) of the stern shaft seal in actual operation is calculated as 2 drops / min, it can be calculated that the allowable oil leakage amount (normal consumption value) of a dual-shaft ship per day is 24 × 60 × 2 drops / min × 2 axes (equivalent to about 288ml / day). In this way, the annual leakage of the stern shaft seal of each ship is about 105 L / year under normal conditions. A 3 000-ton container vessel with a good condition, maintenance specifications, and a stern shaft seal without any sudden oil leakage accidents during the period, the data we obtained is that the annual oil leakage of a single stern shaft seal (normal (Consumption value) usually 50 to 70 L / year. In this way, the oil leakage of a single ship under normal conditions is 100 to 140 L / year.

According to relevant statistical data, there are nearly 10,000 ships of all types sailing
in the Three Gorges Reservoir area all year round. According to the above calculation, the stern tube leakage of oil will reach about 1 000 t per year. If the oil leakage of various abnormal reasons is added, such as: the stern shaft seal itself does not meet the standard, minor damage has not been repaired or replaced, and the oil leaked (released) when the stern shaft is repaired and disassembled by the coastal shipyard in the reservoir area, the ship replaces the stern. The oil released from the shaft seal (this method is currently used by a large number of private ships), and the sudden leakage of oil caused by the winding of the stern shaft seal during the operation of the ship in recent years. If this situation continues, maybe one day in the near future, we can intuitively see the large area of oil pollution floating on the surface of the Three Gorges River in the 600 km stretch of the Yangtze River.

In the past, due to the rapid flow of the Yangtze River water and its own purification ability, the stern tube seal was difficult to form intuitive pollution to the river water due to oil leakage. But since the completion of the reservoir area, the fluidity of the river water has greatly weakened, and its own purification function has become worse and worse. If this sudden oil spill cannot be effectively controlled, and the oil pollution is always floating on the water, it is difficult to flow into the sea through the sluice hole under the Three Gorges Dam. The cumulative effect of pollution will become more apparent over time.

According to some published documents, the "closed water lubricated stern stern tube system" has already been used in mature cases, which has solved the problem of high cost of ship reconstruction and maintenance, and has good application and promotion value.
2.3 Current response measures on oil pollution and related conventions

2.3.1 Relevant provisions of international conventions and economic compensation for oil pollution damage

With the frequent occurrence of ship oil pollution accidents, the international community gradually realized the seriousness of ship oil pollution damage. (Si YZ, 2007) Since the 20th century, in order to control ship oil pollution, the international community has issued corresponding international conventions and regulations. At the same time, the pure economic loss compensation for ship oil pollution accidents has also been a long and solid exploration. (Zhang HB, 2014) In April 1954, the United Kingdom organized international conferences held by governments in London. The conference promulgated the International Convention on the Prevention of Marine Oil Pollution, which was the first international convention to prevent and control oil pollution from ships. But there are no regulations on compensation for damages caused by ship oil pollution accidents, and there are no related problems related to compensation for pure economic losses caused by ship oil pollution. The scope of compensation for oil pollution of ships stipulated in CLC1969 is limited to the loss of damage caused by oil pollution, and also includes the costs required to take reasonable preventive measures, but does not include pure economic losses. In order to fully protect the legitimate rights and interests of the victims and obtain a reasonable amount of compensation, in December 1971, the CLC-based IPOC was passed. The Convention is an international convention that provides full compensation to victims of oil pollution from ships and supplements the deficiencies of CLC1969. However, it does not involve the problem of pure economic loss caused by oil pollution from ships. At the same time, in order to match with CLC1992, Fund1992 was adopted on December 17, 1992. The Convention has relevant provisions on compensation for pure economic losses caused by oil pollution from ships, and clarifies the purpose of preventing or reducing the occurrence of pure economic losses caused by oil pollution from ships. Additional reasonable expenses...
In order to process and resolve claims for oil pollution incidents caused by non-oil tankers, the International Maritime Organization issued the 2001 Fuel Oil Convention in 2001. The main purpose of the convention is to solve the pollution accidents caused by the leakage or unloading of ships' fuel oil. Unlike the scope of CLC1969, which is only applicable to oil tankers, it is applicable to all ships, even offshore drilling platforms, which makes up for the loopholes of the previous international conventions on oil pollution regulations. The provisions of the Convention on damages are stipulated in the definition of "oil pollution damage" in Article 9, paragraph 1. Although the pure economic loss of oil pollution is not explicitly mentioned, the scope of compensation includes damage and loss caused by oil pollution. It also affirmed the compensation for the cost of preventive measures and loss of profit, and recognized the compensability of the pure economic loss of ship oil pollution from the side.

This paper argues that these conventions focus on accidents involving large tankers and other ships. These accidents have a wide social impact, but the leakage of stern tube oil is often overlooked. There is also a lack of pertinent requirements of some conventions. The oil leakage of the stern tube is highly concealed, but it occurs at any time. The fundamental way to solve the oil leakage pollution of the ship stern tube seal is to change the existing ship stern shaft stern tube oil lubrication to water lubrication.

Ship stern tube water lubrication system is divided into "open water lubrication system" and "closed water lubrication system" according to the structure. At present, many high-speed ships along the coast and inland rivers choose to use "open water lubrication system". In recent years, some domestic institutions in China have begun to study "closed water lubricated stern tube system", that is, without changing the structure of the existing ship stern tube system, the lubricating oil in the system is
directly used with clean water or non-toxic. The harmless replacement of water-based lubricating fluid, on the one hand, meets the requirements of the ship for maintenance-free periods of the stern shaft and stern tube system, reduces the use and maintenance costs, and at the same time can also meet the needs of the environmental protection of the reservoir area, and achieve social and economic benefits.
CHAPTER 3. Technical characteristics of ship stern shaft lubrication system

3.1 The main components and characteristics of the two lubrication systems

According to the type of lubrication, there are two types of stern tube and tail tube devices: water lubrication and oil lubrication. (Zhang, 1985) Figure 1 is the open water lubricating stern tube tail pipe assembly. It is suitable for ships sailing in clean water and sediment-free waters. This type of stern shaft stern tube device has only the first sealing device to prevent seawater from flowing into the ship. The water for cooling and lubricating the bearing may be the seawater after cooling the main engine. The seawater discharged from the main engine seawater cooler is connected to the stern shaft and tail pipe device through the first sealed water inlet. After cooling the lubricating bearing, it is discharged outboard.

Figure 2- Open water lubricating stern tube device

Source: Guo Xianming (2004). Feasibility Study on Closed Water Lubricated Tail Shaft

Figure 3- Closed oil lubricating stern tube device
Figure 3 is an oil-lubricated stern tube device, which is mostly used for ships sailing in inland rivers and coastal muddy sands. The closed system is composed of tail pipe, white metal bearing, head and tail sealing device, oil tank and its pipeline, etc., and lubricating oil is used as cooling and lubricant. Due to the closed structure, the silt water is effectively isolated, avoiding the wear of the silt on the stern shaft and bearing, and extending the service life of the stern shaft and bearing.

The stern tube oil seal system is a kind of oil seal system relying on gravity. The traditional gravity lubricating oil sealing system is shown in Figure 3. Among the three sealing rings behind the seal, #1 and #2 sealing rings are seawater sealing rings, and #3 sealing ring is an oil sealing ring. As long as the liquid level of the gravity oil tank is higher than the maximum draught of the ship, the oil pressure on the inside (concave side) of the #3 "J" type sealing ring can be higher than the pressure of the external seawater to achieve the purpose of sealing, the stern tube oil does not leak. The design of the "J" sealing ring itself is to allow the concave side to withstand greater liquid pressure, so the concave side of the #1, #2 sealing ring is outward, which plays the role of sealing the seawater and protects the tube. However, since the gravity oil tank is used to meet the maximum draught of the ship, the oil pressure in the stern tube is constant. Therefore, when the ship is under light load draught, the pressure difference between the inside of the stern tube and the outside seawater is large, which is easy to cause damage to the sealing ring and thus lose the sealing effect. Especially when the propeller has large vibration or sea damage causes the tail seal device to fail, the lubricating oil in the tail pipe will leak a lot. It has polluted the water environment and caused economic losses. This is a fatal flaw of the oil lubricated stern tube and oil stern tube device. (Zhang, 1985)
3.2 Technical alternatives to retrofit water lubrication systems

3.2.1 Open type water lubricated stern tube device

At present, the open water lubricating stern tube device has been widely used in ships with clean water and sediment-free waters such as oceans, lakes and reservoirs. The first sealing device and bearings have mature products; anti-corrosion to the carbon steel stern shaft Measures (shaft covering) also have mature experience. The water groove on the water lubricated bearing is used to discharge the sand and sand from the stern tube to prevent the sand and sand from staying between the bearing and the bushing to wear them. In addition to the wear resistance of the bearing material itself, the sediment content in the lubricating water also has an important impact on the service life of the bearing. Especially for some large commercial ships, if the low sediment content in the lubricating water can be ensured, the lubricating water groove
at the lower part of the bearing can be removed during the design to increase the bearing capacity of the bearing by more than double, thereby greatly shortening the bearing design size and increasing the wear life, making water-lubricated stern bearings replace oil-lubricated bearings in service life. The whole system pipeline is shown in the 5

Figure5- Water lubrication with water treatment equipment

Source: Author

At present, the water treatment device products of Thordon and Wärtsilä almost monopolize the entire water-lubricated ship industry. The structural design and principles of the two products are almost the same—they both use cyclone filter separation technology, which covers a small area and is suitable for space. It is used in limited cabins, but it is expensive, and the filter is easily blocked during long-term use. It needs to be disassembled and cleaned frequently, which not only reduces the processing capacity, but also increases the labor intensity. The accuracy is not high, and the overflowing water still contains a certain amount of sediment. In addition, from the sewage inlet to the sediment outlet section, the sediment content is high. During the long-term use, the inner wall of the pipeline is continuously washed away by the sediment, and the phenomenon of wear and collapse sometimes occurs, and the pipeline needs to be replaced from time to time.

Based on the current status of water treatment equipment, some Chinese companies
have innovatively improved the structural design of water treatment equipment based on the advanced product structure performance of some companies. The device adopts inverted cone design and outer filter screen to realize the function of centrifugal separation of impurities and self-cleaning of the filter screen. Solid particles with large specific gravity can be efficiently separated out, eliminating the need for disassembly and washing. This technology is currently used in the land wastewater treatment industry. Taking into account the particularity of the application of the ship, a special cyclone separation device for seawater corrosion and erosion resistance can be developed. The maturity of the water processor has basically reached the level of international products and can be put into use. The treatment of wear-resistant materials in the pipeline can also improve the product life better.

The stern tube cooling water purification device is composed of an electric control box, a cyclone separator, an electric control sewage valve, a pipeline and a frame. According to customer requirements, functions such as flow monitoring and alarm, pump control, automatic / manual switching, and system redundancy can be added to meet the various special requirements of different customers and different ships. Different materials are available for the cyclone separator, including: SS316, SS316L, 90 / 10BFE. The remaining materials can also be customized. The cyclone separator can remove 98% of solid suspended particles with a specific gravity greater than 1.2 and a diameter greater than 40um. The working temperature of the cyclone separator is not higher than 100 ℃, and the pressure is not higher than 7Bar. During the drainage process, the flow rate of the outlet pipe will decrease for a short time (about 10s). If the flow rate is not reduced, check whether the sewage pipe is blocked and perform the necessary cleaning. The basic function of the electric control box is to automatically drain and manually drain the sewage valve at regular intervals. It can also cooperate with the flowmeter to realize the flow direction display and alarm according to user needs. The alarm signal can be transmitted to the engine room central control room or other areas. For the dual-pump stern tube water purification device, combined with flow control, the electronic control box can realize automatic
switching of the standby swirl separation branch, which improves the safety of ship operation.

The idea of the next generation is to make the water processor intelligent, which can automatically adjust the speed of the pump according to the changes in water temperature and pressure detected by the sensor to control the water intake. When the water temperature and pressure exceed the upper limit, the power can be forcibly turned off. The system prevents the bearing from being further damaged and causing shaft failure. At the same time, in order to prolong the service life and solve the problem of the pipeline being damaged by the impact of sand cutting, we designed to spray a layer of 1-2 mm in wear-resistant polymer engineering materials are being tested for spraying and adhesive destruction of materials.

3.2.2 Closed water lubricated stern tube and tail pipe device (need to be changed)

Figure 6 - Closed water lubricating tail pipe device
As shown in figure 6, the closed water lubricating tail shaft tail pipe device is provided with a head and a tail sealing device. The head and tail bearings and rubber seals are lubricated and cooled by fresh water. Fresh water is pumped into the first sealing device by the cooling water pump. The first sealing device for cooling and lubrication, the front and rear bearings, and the tail seal are returned to the fresh water tank for recycling. The pressure value of the pressure gauge can be used to judge whether the cooling water pump is working normally. The alarm signal from the low level switch can be used to know that the water level of the fresh water tank is low. For the reliability of the system, a forced water circulation system is used for lubrication and cooling. For ships with some or most of the stern pipes outside the hull and submerged in water, the amount of circulating water in the system can be reduced.

![Diagram of sealing device](image)

**Figure 7-Forward and rear seal**


The front sealing device can use SM series water lubricating sealing device produced by Jiangsu Dongtai Marine Parts Factory. This device has been widely used in coastal and ocean-going ships. As shown in the figure, the front sealing device is composed of a casing, a static grinding ring, a sealing ring and a pneumatic tire. The actual function is the sealing surface between the sealing ring and the static grinding ring. The static grinding ring can be made of bronze through precision processing. When
the rubber sealing ring rotates with the tail shaft, the lip is in close contact with it to ensure that the cooling water does not leak. In case the seal ring is worn, the inflatable tire can be used for emergency sealing. Cut off the worn seal ring, move the spare seal ring to the specified position and put it into work, no need to dock or disassemble the shaft system in the upper row. Therefore, it can provide the maximum security under the premise of least cost.

The stern tube sealing device can use the MapromGS SEAL type product produced by Maprom Engineering B. V., as shown in the figure. The sealing ring of the front and rear directions of the tail shaft sealing device 1 # and 2 # and the double-sided polished static grinding ring are the keys of the tail seal. The protection system prevents the water containing sediment from entering the circulation system. The two sealing rings are made of wear-resistant synthetic rubber, and the sealing lip of the sealing ring is in contact with the surface of the static grinding ring to achieve axial and radial sealing. The sealing ring is tightened on the shaft by a ring-shaped spring, so that it rotates together with the shaft. This type of structure has a good sealing effect even when the tail shaft is vibrated.

3.3 Development and research status of water lubricated bearing materials

3.3.1 Main classification of water-lubricated bearing materials

The early water-lubricated bearings were mainly made of iron pear wood, which had higher density, hardness and very good self-lubricating effect. However, it has a certain degree of water swelling and poor tolerance to foreign objects. It is not suitable for ships sailing in waters with a large amount of sediment. It is not suitable for installing iron pear wooden bearings, and it is expensive. For this reason, the development of new types of water-lubricated bearing materials with superior performance has become a hot spot for researchers, such as ceramics, rubber, nylon, plastics, and ultra-high molecular weight polyethylene.
(1) Wood materials
Iron pear wood material is the earliest used and oldest ship water lubricated stern bearing material, also known as guaiac wood, is a wood material with excellent performance. Iron pear wood is characterized by high hardness, high strength, and long service life, being not easy to be corroded and the friction coefficient in the seawater paired with the copper alloy shaft is very small, and the friction performance is relatively good. (Jin, 1981) As a material of ship stern bearing, iron pear wood has the longest history of practical application and the widest range of applications. However, Pearwood is only produced in South Africa, and there is no Pearwood in other places. Due to the wide application demand, the resources of big iron pear wood are decreasing day by day. Iron pear wood has poor resistance to sediment and poor performance in a sediment environment, and the application environment is limited. (Wang, JX 2002)

Because the production of iron pear wood is relatively small, the production area is limited to South Africa, and it only depends on imports, which cannot meet the demand and is expensive. Therefore, it is necessary to find alternatives. Laminate is one of the better and ideal materials. The more commonly used laminate materials mainly include birch laminate and cloth laminate. The birch laminate has many advantages, such as good corrosion resistance, stable size, small friction factor with the friction surface of the journal, and simple processing technology and low cost. However, compared with the iron pear wood, its wear is much larger under the same conditions, and its wear resistance is poor. The heat generated during operation is relatively large. (Peng, 2001) If the supply of cooling water is insufficient, it will have a greater impact on its performance. In severe cases, the heat of the bearing will be too large to operate normally.

(2) Metal materials. The hardness and elasticity coefficient of metal materials are generally relatively high and wear-resistant. The clearance of water-lubricated
bearings is stable during the operation of the bearings. The coefficient of expansion in water is small. The dimensional stability of the bearings is good, which can ensure the accuracy of the tail bearings. Therefore, under the boundary lubrication conditions of low speed and heavy load conditions, its superiority can be more reflected. However, the buffering ability to the load is very poor, making it difficult to form a water film. Due to the relatively high hardness of metal bearings, which determines the poor resistance of foreign materials in metal tail bearings, it can not be used in waters mixed with debris, especially in the waters containing impurities such as sediments in the Yangtze River. Metal stern tube bearing materials are prone to contact with water due to electrochemical reactions and cause corrosion problems. (Qin, 2012) At the same time, metal materials and water will be more prone to chemical reactions. The oxide generated by this chemical reaction will have an adverse effect on the lubrication of the stern tube bearing.

(3) Ceramic materials are made by processes such as injection molding and high-temperature sintering of natural compounds or synthetic compounds. The main advantages of ceramic materials are high strength, relatively high stiffness, good thermal conductivity, good wear resistance, low friction factor, good corrosion resistance, high temperature resistance, high melting point, small coefficient of thermal expansion, and bearings. The gap is stable and the size of the bearing is relatively stable, which can ensure that the accuracy of the ceramic tail bearing is not affected. Compared with traditional bearing materials such as metal and polymer materials, bearings made of ceramic materials are particularly suitable for working in special environments such as high temperature, high shaft speed, strong magnetic field and strong corrosive environment, and special media such as seawater. Therefore ceramics can also be used as water-lubricated bearing materials.

However, ceramic materials also have many obvious shortcomings that restrict their wide application as ship stern bearing materials and promotion of ceramic materials as ship stern bearings. Their casting and processing are more complicated. The
cushioning performance of ceramic materials is very poor and resistant vibration performance can be very poor and the texture is relatively brittle. At the same time, due to the poor immersion of foreign materials in the ceramic material, in the water area where the water quality is not clean enough, the friction surface of the ceramic bearing and the shaft is prone to serious friction and wear due to impurities in the water, which causes damage to the bearing and the shaft and shortens its service life. As a result, the operating cost of the ship increases and the time it takes to replace shafts and bearings due to shorter life is increased. When the wear is severe, it may even cause damage to the safety of the ship and cause inestimable adverse consequences.

(4) Rubber material. The rubber material will produce great elastic deformation under certain conditions. The difference with other materials is that the rubber material can be completely restored almost immediately after the deformation force is removed, especially after the rubber is used in the manufacture of water-lubricated bearings. The factor is always far lower than the friction factor of metal bearings, that is, the friction and wear performance of rubber bearings is better than metal bearings. Because rubber has a small elastic modulus, it has a strong recovery ability after deformation, so water-lubricated rubber bearings can still operate normally under the harsh conditions with abrasive particles or impurities mixed, and will not cause a large damage. Rubber bearings also have certain deficiencies. Once the rubber bearings are supplied with insufficient lubricant during the start and stop process, it is easy to wear, stick and scorch, which will cause the bearings to fail to operate normally.

(5) Engineering plastic materials. Because engineering plastics have more advantages and functionalities, they are more and more widely used in the field of machinery. They gradually replace metal friction parts and become the most popular water-lubricated bearing material. At present, ultra-high molecular weight polyethylene, nylon, etc. are widely used in plastic lubricating bearings. They are all
excellent water-lubricated bearing materials. Ultra-high molecular weight polyethylene has high mechanical strength, good wear resistance, low friction factor, non-toxicity and recyclable recycling. It is a new type of thermoplastic engineering plastics which have been widely used in making water-lubricated bearings.

Nylon as a bearing material is a synthetic fiber first developed by the American scientist Carothers and his research team. Nylon as a water-lubricated tail bearing material has good self-lubricating properties and a high friction factor, but its wear resistance is relatively good. Nylon materials have been widely used in light-load bearings. However, the nylon material has strong water absorption, which easily makes the dimensional stability of the tail bearing poor after the size of the nylon bearing meets water. The bearing size will change greatly in water, affecting the accuracy of the tail bearing. This is also a very fatal weakness of nylon in water lubricated bearing applications.

UHMWPE is a new type of thermoplastic engineering plastic with linear structure. It has excellent wear resistance, low friction coefficient, extremely high impact strength, high hardness, good vibration and noise resistance, low friction factor, easy to attach foreign objects, cheap price and low cost, and a wide range of working temperature. The advantages of non-toxicity, pollution-free, recyclable recycling and environmental protection have been widely used, and they have also been gradually applied to water-lubricated bearings.

However, the UHMWPE I has poor water absorption performance, that is, poor hydrophilicity, and it is difficult to form a water film under hydrodynamic lubrication under actual working conditions.

6) Modified composite materials
Since the comprehensive performance of a single material is generally not ideal, there is no perfect bearing material, so the development of new composite materials through blending modification is currently a very popular research direction. Through the mixing of two or more substances, the strengths and weaknesses are selected, and
the advantages of the various properties of the two materials are selected to be integrated to improve the overall performance of the material. Thordon material is a successful example of blending modification, and its overall performance has been greatly improved after blending modification. Thordon material is a blend of ultra-high molecular weight polyethylene, graphite, and vulcanized rubber. The main advantage of the compound material after blending modification is that the bearing capacity has been improved a lot, which can better adapt to the heavy load working conditions, and at the same time can greatly reduce the length-diameter ratio of the tail bearing, thereby reducing the size of the tail bearing. The weight makes the ship more flexible and lighter, which has outstanding significance for warships and submarines. After the modification, the hardness of the material has been greatly improved, and the mechanical processing can be directly and conveniently performed, the processing technology becomes simpler, and the processing cost is lower. After the modification, the material has good wear resistance, and the wear on the shaft is small during the operation of the shaft, which can effectively extend the service life of the shaft and the tail bearing, which not only saves operating costs but also saves times due to the extension of the shaft and bearings. The saved time for repairing and replacing shafts and bearings can improve economic efficiency and is mainly used on large surface ships.

3.3.2 Research content of water lubricated bearing materials
Since the viscosity of water is lower than that of oil (only 1/20 ~ 1/100 of oil), the bearing capacity of water film is much smaller than oil. The bearing capacity of water lubricated bearings is not as good as oil lubricated bearings. Water-lubricated bearings and shafts act as a pair of friction pairs. The factors affecting the friction performance of water-lubricated tail bearings and shafts are mainly the following: relative sliding speed of shaft and bearings, bearing load, temperature of lubricating water, structural characteristics of tail bearing, cleanliness of lubricating water quality, gap size of tail bearing installation, length of operation of propulsion system, matching materials of bearing and journal, roughness of friction surface of bearing and journal, water flow
rate, etc. At present, the main research method is generally to design and measure the change trend of the friction coefficient under the specific working conditions that keep other parameters unchanged and only a single factor, and study the change characteristics of the friction coefficient under the change of the single working condition factor. The factors affecting the coefficient of friction of the tail bearing, as well as the influencing trend and degree of the influencing factors are listed. It can provide theoretical basis and support for the design and preparation of tail bearings.

The study of the wear characteristics of bearings is mainly due to the following aspects: lubricating medium (fresh water, water containing sediment, sea water, the size of the load, the speed of the rotation, the length of the running time, the roughness of the friction surface of the bearing and the journal, The characteristics of the matching materials of the bearing and the journal, etc.
CHAPTER 4 Research on tribological mechanism and analysis of friction and wear properties of high-quality alternative materials

4.1 Research on friction and wear properties and tribological mechanism of high-quality alternative materials

4.1.1 Boundary conditions for the simulation study of water-lubricated bearings

When people perform numerical calculations on a physical problem or a mechanical problem, they must first establish a certain mathematical model. The study of the mechanism of water lubrication is relatively complicated. In order to facilitate the study and find out the laws of each state of water lubrication, it is necessary to simplify the model using mathematical methods. Numerical calculation is an ideal situation. In order to make it close to the actual problem, some constraints must be added to the mathematical model. These conditions are usually called boundary conditions. When calculating the lubrication performance of water-lubricated bearings, the researchers gave three more reasonable conditions, namely:

1) Sommerfeld boundary conditions
This boundary condition made the following assumptions about the lubricating fluid in the bearing gap before the calculation: the lubricating fluid is sufficient in the bearing gap; the distribution of the lubricating fluid film is continuous throughout the model, and there is no area where the liquid film is broken. The pressure distribution of the liquid film in the circumferential direction of the bearing is a periodic function that changes with the rotation angle. It is a positive value in the range of $0 \sim \pi$ and a negative value in the range of $\pi \sim 2\pi$. The pressure distribution of the entire liquid film is $\varphi = \pi$, that is $h = h_{\text{min}}$, the value is expressed as:

$$p (\varphi) = p (\varphi + 2\pi)$$

$$P = 0 (h = h_{\text{max}})$$


During actual shafting operation, the lubricating fluid film is not necessarily a periodic function in the circumferential direction and is antisymmetric, nor is it continuously distributed throughout the bearing. There must be an area where the lubricating fluid film ruptures, so this boundary condition is too ideal. However, using this boundary condition to solve the Reynolds equation is quite simple. When the calculation accuracy is not high, it can be used for theoretical analysis.

2) Gumbel boundary conditions

The difference between the Gumbel boundary condition and the Sommerfeld boundary condition is that neither the lubricating liquid film is continuous nor the pressure generated by the lubricating liquid film is continuous in the entire bearing lubrication area, but it is considered to be continuous only in the hmax to hmin The distributed liquid film pressure, from the next hmin to hmax, does not generate pressure due to the rupture of the liquid film, and there is no pressure distribution. During the actual rotation of the shaft system, the distribution of the liquid film pressure is not cut off at hmin, but is broken at some place after it. The value is expressed as:

\[
p \geq (0 \leq \phi \leq \pi) \\
P = 0 (\pi < \phi < 2\pi)
\]

3) Reynolds boundary conditions

The Reynolds boundary assumes that there is a crack in the bearing lubricating fluid film, and that the crack cannot be determined directly, but by calculation. If the pressure of this node is a negative value of \(p\) in the calculation process, this point is the end point of the pressure distribution of the lubricating liquid film, and the pressure \(p\) of several subsequent nodes are all assigned 0. which is

\[
P (i, j) = 0. \text{ if } i = 1 \ldots m, \text{ j = 1 \ldots n}
\]

In summary of the above three boundary conditions, the Reynolds boundary condition is the closest to the actual situation of bearing lubrication during the operation of the
shaft system, although there are still assumptions in many aspects.

4.1.2 Five lubrication states of the bearing under water lubrication

By studying the classification of the lubrication state, we can find the core problem to solve the bottleneck of bearing life, and then extend the stability and life of the water lubrication system. Lubricating technology is used to separate the two surfaces with relative movement so that the two no longer contact and ensure that the two surfaces will not cause greater wear. The so-called lubricant is simply a substance between two relatively moving objects (or friction pairs), which has the effect of reducing friction and wear due to contact. Lubricants come in many forms, and can be gas, liquid, or solid. They are added between two friction pairs that move relative to each other to reduce friction and wear. Fluid lubrication can be divided into the following five lubrication states from its lubrication mechanism: fluid dynamic pressure lubrication, hydrostatic pressure lubrication, elastic fluid dynamic pressure lubrication, boundary lubrication and mixed lubrication.

1) Fluid dynamic pressure lubrication

There is a wedge-shaped gap between the inner surface of the bearing and the outer surface of the journal. When the shaft system rotates, the journal will deviate from the shaft center, and at the same time, the lubricant will be drawn into the bearing by the shaft system. In the direction of shaft rotation, from the top to the bottom of the bearing, the lubricating fluid film gradually generates pressure and separates the bearing from the journal. The lubricating fluid film completely separates the inner surface of the bearing from the outer surface of the journal, that is, hydrodynamic lubrication.

To form fluid dynamic pressure lubrication, the following three conditions must be met:

(1) The lubricant between the two sliding surfaces of the inner surface of the
bearing and the outer surface of the journal has sufficient viscosity

(2) There is sufficient relative movement speed between the bearing and the journal;

(3) There must be a certain gap between the inner surface of the bearing and the outer surface of the journal, that is, the geometry of the fluid wedge is a wedge.

2) Hydrostatic lubrication

Hydrostatic pressure lubrication can also be called external pressure lubrication. Compared with fluid dynamic pressure lubrication, the lubricant at this time is not brought into the friction pair by the movement of the moving parts, but is artificially pressurized and sent into the cavity. It is used to separate the shaft from bearings or other similar moving parts and to bear the external load on the system. And regardless of the speed of the shaft or other similar structures, the speed can offset the external load. This effect is the most significant feature of hydrostatic lubrication. The fluid dynamic pressure lubrication requires that the relative motion speed between the bearing and the journal must be sufficient for the lubricating liquid film to be completely formed. Otherwise, there will be direct contact between the two, and friction loss or other damage will occur in the contact area. To a certain extent, the working life of the bearing is shortened. The advantages of hydrostatic lubrication are: low friction resistance at start-up, long service life, wide speed range, good vibration resistance, high motion accuracy, and adaptability to various requirements. The disadvantage is that it needs to be equipped with oil equipment sometimes even requires an extra spare device, which increases the space and weight of the equipment.

3) Elastic fluid dynamic pressure lubrication

During the lubrication process of the friction pair, if the external load on the system is too large, the lubricating fluid film must generate excessive lubrication pressure to completely separate the two relative moving surfaces. The excessive pressure of the lubricating fluid film will inevitably lead to elastic deformation of the structure with
low elastic modulus. This lubrication state is elastic fluid dynamic pressure lubrication.

Elastic fluid dynamic pressure lubrication as a major research progress in fluid dynamic pressure lubrication, the discovery of this phenomenon further improves the fluid lubrication research system. Elastohydrodynamic lubrication initially studied the lubrication characteristics of point contact or line contact friction pairs. The contact stress of this type of friction pair is quite high, basically between 1 ~ 4Gpa. The huge contact stress will not only cause elastic deformation on the surface of the friction pair, but also change the viscosity of the lubricant and produce the viscosity of the lubricating liquid film. Effect, and finally affect the lubrication state of the friction pair to make it into dynamic pressure lubrication. In fact, referring to the traditional lubrication theory that has been studied, under such harsh conditions, the lubricating medium cannot form a lubricating liquid film between the surfaces of the two friction pairs. It is also impossible to separate the two friction pairs in the gap between the surfaces of the two friction pairs by liquid film pressure to form fluid lubrication. However, researchers have found in a long time of practical application that the friction pairs with relatively high contact stress such as gears and rolling bearings have excellent lubrication conditions. Even after a long period of high-strength use, the surface still has no particularly obvious friction and wear marks. From this phenomenon, the researchers have drawn a different analysis from the traditional lubrication theory: the surfaces of the two friction pairs are still separated by the lubricating liquid film when the contact stress is quite high. The researchers believe that this is because the traditional lubrication theory does not consider the viscous pressure effect of the lubricating medium and the elastic deformation of the friction pair under pressure, and these two points can effectively improve the bearing of the lubricating liquid film between the friction pairs ability.

4) Boundary lubrication

In the boundary lubrication state, due to the interaction between the lubricating fluid
and the metal or other solid surface, an extremely thin layer of lubricating fluid film will be produced between the friction surfaces. And the lubricating liquid film plays the most important role in the friction process. The lubricating fluid film in boundary lubrication does not obey the laws of hydrodynamics, and the friction and wear between the two friction surfaces do not depend on the drilling degree of the lubricating fluid, but are determined by the nature of the friction surface and the characteristics of the lubricating film. Since the concept of boundary lubrication, the theoretical research on boundary lubrication has achieved certain results. Bowden model, Adamson model, Kingsbury model, Cameron model, TFL model and other models have been proposed successively. Recently, boundary lubrication research has entered the stage of molecular behavior and molecular film lubrication research.

5) Mixed lubrication
In the actual friction and lubrication process, each of the above-mentioned lubrication states does not exist in isolation, and it is often accompanied by other forms of lubrication. This lubrication state is mixed lubrication.
In the early days of research, it was generally believed that mixed lubrication was composed of dry friction, boundary lubrication and fluid lubrication. However, in recent years, researchers have found that the micro-elastic fluid lubrication film has a flattening effect on the peak of crude sugar, and at the same time has a certain understanding of film lubrication. Wen Shizhu and others put forward the following views on mixed lubrication:
(1) The mixed lubrication state is composed of the following four lubrication states: boundary lubrication, thin film lubrication, micro-elastic fluid lubrication, fluid dynamic pressure lubrication, etc. The lubricating film under various lubrication states is based on the film thickness as its main feature, and their formation mechanism, lubrication characteristics and failure criteria are different.
(2) The overall characteristics of the mixed lubrication state are composed of the characteristics of the lubricating film under the above four lubrication states. The proportion of various lubricating films on the contact surface is determined by the
shape of the friction interface and the operating conditions. The proportion and
distribution of various lubricating films during the friction process are constantly
changing, so the mixed lubrication characteristics has a strong time variability.

(3) An important feature of mixed lubrication is that its friction surfaces are
accompanied by wear. The main forms of surface wear are contact fatigue mechanism
and adhesion mechanism. These two wear mechanisms are determined by
environmental media and operating conditions.

(4) The dynamic stress in the friction process is borne by the surface layer material
and causes the surface layer material to undergo elastoplastic deformation. The stress,
strain, surface bearing volume and material strength during movement are
time-varying. Normal wear caused by mixed lubrication is mechanical wear. Mainly
caused by contact fatigue and micro-cutting of abrasive grain movement.

4.1.3 Conventional modification methods of polymer composites

As can be seen from the previous section, the optimal working condition of the
lubrication state is boundary lubrication. Therefore, in the process of research and
development of new materials, there are two main ideas for measuring the quality of
materials. One is to let the bearing reach the boundary lubrication in the shortest time,
and the second is how to keep the bearing in the boundary lubrication state as much as
possible in the entire working state.

Judging from the order statistics in the new shipbuilding market at present, civil
commercial ships lubricated with water are often selected as modified polymers. The
modification of the polymer is to add fillers during mixing, such as solid lubricants
and fibers, fibers and nanoparticles, etc., which can play a synergistic effect between
the components. To a certain extent, it overcomes the deficiencies of a single filler, so
that the composite material has more excellent friction and wear performance.
Modern chemistry mainly uses the following modification methods to improve the
overall performance of water-lubricated bearings:
(1) Polymer blending modification
Different polymer materials have their own advantages and disadvantages. By blending and using the advantages of polymers to improve the tribological properties of polymer materials under water lubrication conditions, it is one of the effective methods to obtain high-performance water lubrication materials. After the polymer is blended, the addition of the second phase can eliminate the weakness of the performance of the single polymer component. For example, blending UHMWPE with PA6 can reduce the friction coefficient of PA6. The UHMWPE particles dispersed in the PA6 matrix act as a lubricant during friction. At the same time, UHMWPE reduces the water absorption of PA6, improves the dimensional stability, and thus improves the abrasion resistance of the blended material. PI, PEEK, PHBA can not only improve the bearing capacity of the PTFE matrix, but also effectively prevent the PTFE crystal tape from being pulled out. The wear resistance of the PTFE composites obtained after blending with them is better than that of pure PTFE materials.

(2) Fiber reinforced modification
Polymer-based fiber composite materials have higher strength. While improving the dimensional stability, strength, toughness, and environmental resistance of the composite materials, they also significantly improve the tribological properties of the composite materials under water lubrication conditions. There are four types of wear of fiber composite materials under water lubrication conditions: matrix wear and fiber thinning, fiber damage, interface debonding, and fiber spallation. Among them, the debonding of the fiber material from the matrix and the flaking of the fiber are the most important reasons for the wear of the fiber composite material. The main mechanism of fiber reinforcement is that the high-strength fibers exposed by wear carry most of the load on the contact surface. After the fiber is stripped, the matrix material directly contacts the dual due to the lack of fiber load, which is easily damaged by the micro-plowing effect of the rough peak of the dual during sliding.
The presence of various fibers can reduce the fatigue wear of composite materials. Friction pair contact morphology Due to the presence of rough peaks and waviness, surface contact is discontinuous. During the friction process, the contact peak is subjected to cyclic load. Under the action of this alternating stress, the composite material will produce fatigue failure. During fatigue crack growth, in addition to dissipating part of the energy through the interface between the matrix and the fiber, the presence of the fiber will also have a certain effect on the crack growth. At this time, part of the energy will be used for the deflection of fiber breakage or cracks, and the fatigue wear of the composite material will be reduced.

Fabric-reinforced polymer composite refers to a type of composite material that uses a polymer as a matrix and various fiber fabrics as a reinforcement. In the fabric composite material, the fabric as the reinforcement is woven from the same fiber or different fibers through various methods, and is distributed as a continuous whole in the composite material. Compared with other fiber-reinforced forms (such as short fiber or long fiber), the fabric structure has higher order, tightness and integrity. These characteristics of the fabric structure give the fabric composite many excellent characteristics, such as: better structural stability and higher load-bearing capacity, more suitable for the molding process, better suitable for curved surfaces to avoid wrinkling, two in warp and weft The direction has high mechanical strength and so on. At present, many commercial water-lubricated bearing materials use polyester fiber woven materials with added solid lubricants, such as Orkot's TXM Marine.

(3) Modification of solid lubricant filling
The solid lubricants commonly used in polymer materials are mainly graphite, Mo S2, PTFE and so on. Graphite and Mo S2 are both layered structures. Due to their easy shearing properties between layers, they exhibit good lubricity. PTFE has a special long linear molecular structure. In the friction process, it can form a low-shear strength transfer film on the surface of the couple, showing a low coefficient of friction. Zhu Peng uses Mo S2 to fill the thermoplastic PI. Under water lubrication,
the wear rate of the composite material decreases with the increase of Mo S2 content, and the wear resistance of the material is greatly improved. After filling Mo S2, the wear surface is smoother than PI resin, and only cracks appear, showing fatigue wear characteristics. After adding PTFE to PEEK, the compatibility between the two is not good, while the friction coefficient decreases with the increase of PTFE content, the wear rate increases. The friction coefficient of graphite-filled PI composites in water and alkaline solutions is less than that of Mo S2-filled PI composites. Under water lubrication conditions, water molecules hinder the formation of the friction surface transfer film and destroy the filler and the matrix. The bonding effect, especially the hydrophilic filler Mo S2, is easy to fall off from the matrix to cause abrasive wear and increase the wear rate.

(4) Nanomaterial modification
Adding nanoparticles to polymer materials can greatly improve the overall performance of the material. Polymer nanocomposites have the basic characteristics of nanoparticles' own small size effect, surface effect, particle synergy effect, and polymer material itself is soft, stable, and easy to process.
Under water lubrication conditions, inorganic nanoparticles reduce the friction and wear of polymers mainly through two aspects:
The addition of nanoparticles enhances the mechanical properties of the composite material; the addition of nanoparticles enhances the adhesion between the transfer film and the friction pair. The carbon nanotube-reinforced EP composites prepared by Lei Yan have greatly improved compressive strength, compressive modulus and hardness compared to pure epoxy resin.

(5) Multiple compound modification
Adding several fillers into the polymer at the same time, such as solid lubricants and fibers, fibers and nanoparticles, can play a synergistic effect between the composites so that the composite material has more excellent friction and wear performance.
For composite materials composed of multiple materials, the overall comprehensive performance is not a simple summation of the linear relationship of the performance of each single component. Under water lubricating conditions, CF and PTW are added to PEEK, PBO fiber and carbon nanofiber are added to PI, CF, graphite, and CNT (carbon nanotube) are added to PI. It plays a good role in synergy and improves the wear resistance of the material. The main reason for this synergy is the interaction between various fillers.

4.1.4 The key factors affecting the water-lubricated friction and wear of polymer composites

In addition to studying the characteristics of the composite material itself, other factors under water lubrication also affect the stability and life of the water lubrication system. To study the key factors affecting the water-lubricating properties of polymer composites, the overall parameters of the ship and the degree of research and development of other components of the stern tube system can be adjusted in practical applications. The degree of coordination of system parameter debugging directly affects the life of water-lubricated bearings, which in turn affects the safety and stability of the ship.

(1) Speed load

During water lubrication, the friction of polymer composites mainly comes from two basic aspects: one is the furrow grinding process of the hard dual surface micro-convex body on the soft polymer surface; the second is the high stress formed on the actual contact surface the shearing process of sticky points or sticky areas. Fluid dynamic pressure lubrication relies on the lubricating film that generates dynamic pressure effect when the two sliding surfaces of the moving pair move relative to each other, thus separating the moving surfaces. The dynamic pressure effect is one of the main factors that form the pressure of the lubricating film. The increase in speed makes the fluid dynamic pressure effect more obvious. The friction
force generated during the furrow grinding process and the adhesion point or adhesion zone shearing process has been reduced to varying degrees, and the friction coefficient and wear rate have decreased. The increase of the normal load increases the actual contact area, resulting in increased wear and abrasion, but the wear rate at this time has not increased. Since most polymer-based composite materials have viscoelastic properties, the frictional pair of polymer-based composite materials that are in elastoplastic deformation on the surface contact has a non-linear relationship between the actual contact area and the normal load. The coefficient of friction will decrease as the load increases.

Therefore, under water-lubricated conditions, the friction coefficient of most polymers shows a decrease with increasing load and speed. The wear rate generally increases with increasing load and decreases with increasing speed.

(2) Types of water quality
The tribological properties of polymer composites are not only related to the properties of the polymer itself, but also to the lubrication medium. Types of lubricant water include deionized water, sea water, distilled water, physiological saline, and sand-containing water. Considering most practical applications, only the comparison of the lubricating effect of pure water with seawater and sand-containing water is described here. Compared with pure water, the researchers found that seawater has more advantages in lubricating effect. Lancaster found that the wear rate of SCF-enhanced EP and S80 stainless steel when rubbed in seawater is less than that in pure water, and believes that this is due to the seawater's dual corrosion of the metal and its surface polishing and roughness reduction. When seawater lubricates, a layer of slurry like Ca CO3 and Mg(OH)2 can be deposited on the couple, which can not only provide a lubricating effect, but also prevent direct contact between the friction couples.

(3) Roughness of friction couple
When two frictional surfaces are in contact, due to the presence of surface roughness, the actual contact occurs only on a very small portion of the surface area.

Comparison of the roughness and the size of the water film (oil film) can distinguish different fluid lubrication states. Although the formation of various lubrication states is basically due to the difference in the thickness of the lubricating film, the lubricating state cannot be accurately judged simply by the thickness of the lubricating film. These studies still need to be compared with the surface roughness. Only when the thickness of the lubricating film is sufficient to exceed the rough peak height of the two surfaces, it is possible to avoid direct contact of the peak points and achieve full-film fluid lubrication.

(3) Duality
When selecting water-lubricated bearing materials, the selection principle cannot simply rely on the dry friction characteristics exhibited by the materials. It is necessary to add due consideration to the lubrication and cooling effect of water, because such selection principles ignore the physical and chemical properties of the material surface. The wetting angle of the material under water lubrication has a very important influence on the coefficient of friction.

![Diagram](image.png)

Figure 8- Hydrophilic and hydrophobic
Source: Guo Guofan (2013). Research on Friction and Wear Properties and
Tribological Mechanism of Water Lubricated Bearing Materials

As shown in figure C of the figure 8, when the friction pair material is a hydrophobic disc and a hydrophilic pin, the hydraulic lifting effect of water at the friction interface helps reduce the friction coefficient and wear rate of the material. The trend of the friction coefficient of different wettability friction pairs has the following rules: (hydrophilic-hydrophilic)> (hydrophobic-hydrophobic)> (hydrophobic-hydrophilic), the corresponding friction coefficient value change is (0.43~0.56)>(0.23~0.15)>(0.15~0.03).

4.2 Overall renovation project plan evaluation

4.2.1 Comparison of operating and installation costs

Table 1 - Comparison of operating and installation costs

<table>
<thead>
<tr>
<th>Item</th>
<th>component</th>
<th>Amount (ten thousand yuan)</th>
<th>Replacement period (year)</th>
<th>Total (ten thousand yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water lubrication system</td>
<td>Front seal</td>
<td>4.2</td>
<td>5</td>
<td>45.2</td>
</tr>
<tr>
<td></td>
<td>Antiseptic treatment</td>
<td>3.6</td>
<td>5</td>
<td>27.8</td>
</tr>
<tr>
<td></td>
<td>Copper bush</td>
<td>6.4</td>
<td>10</td>
<td>55.6</td>
</tr>
<tr>
<td></td>
<td>Polymer bearing</td>
<td>5.8</td>
<td>2.5/10</td>
<td>51.1</td>
</tr>
<tr>
<td>Oil lubrication system</td>
<td>Front and rear seal</td>
<td>9.8</td>
<td>5</td>
<td>31.9</td>
</tr>
<tr>
<td></td>
<td>Lubricating oil</td>
<td>2.4/12</td>
<td>5</td>
<td>63.8</td>
</tr>
<tr>
<td></td>
<td>White metal bearing</td>
<td>7.5</td>
<td>10</td>
<td>102.2</td>
</tr>
<tr>
<td></td>
<td>Fines for spills</td>
<td>20-50/times</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The reference data in the table is derived from the relatively large number of fishing vessels with a shaft diameter of 270mm and 8,000 tons in the Yangtze River Basin in China. Whether it is oil lubrication or water lubrication, the docking costs are about the same, so this cost is not included in the table.

It can be clearly seen from the table that due to the lack of effective protection measures for polymer bearings in the current traditional water lubrication system. In the 10-year period, polymer bearings cost the most, resulting in higher costs for the overall water lubrication system, which is also the most fundamental reason why the majority of shipowners are reluctant to use water lubrication systems.

Even if the punishment of environmental protection is increased, shipowners replace environmentally friendly oil, the overall cost is only about 6,000 yuan more than the traditional water lubrication system, and the average cost is only 600 yuan per year. Shipowners have no need for transformation. Only through the breakthrough optimization of the water lubrication system, the introduction of the water treatment device can ensure that the life of the polymer bearing is increased from the original 2.5 years to 10 years, which greatly improves the cost performance of the water lubrication system and fundamentally stimulates the economy. The shipowner upgraded the oil lubrication system, and the usual maintenance cost of the oil lubrication system was higher than that of the water lubrication system.
4.2.2 Retrofit cost analysis and risk assessment

Table 2 - Retrofit cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount (ten thousand yuan)</th>
<th>Replacement period (year)</th>
<th>Total (ten thousand yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of changing oil lubrication system to water lubrication system</td>
<td>facility charge 8</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Hourly rate/alteration, replacement of other parts, etc 10</td>
<td>---</td>
<td>23</td>
</tr>
</tbody>
</table>

The data in the table is still estimated based on the fishing vessel with a shaft diameter of 270 mm and 8000 tonnage. There are two main items spent, equipment costs and working hours, which are also not included in the docking costs. In addition, the equipment cost is only the water processor and the intelligent self-testing shafting system, and the seal and the polymer bearing are not included.

The man-hour cost is only relatively high during the initial transformation, because the propeller tail structure needs to be completely redesigned and arranged, and the engineering volume is relatively large. When entering the dock for maintenance and repair later, the man-hour cost can be significantly reduced. Therefore, compared with the 10-year period, the increase in the cost of using 20 years as the statistical period has not shown a multiple increase. And the better the maintenance of the ship in the later period, the longer the service life, the more obvious the economic cost advantage of the transformed water lubrication system.

The following is an analysis of the risk assessment...
(1) Risks of technical solutions
From the construction point of view, the renovation project has almost no risks. However, the shipyard needs to have the ship repair qualifications required by various countries, and the personnel have undergone safety training. Shipyards and suppliers should work together to improve daily work efficiency, strengthen assessment and management efforts, and try not to bring hidden dangers to the later application of the system.

(2) Policy and legal risks
There are no regulatory policies and legal risks in this project.

(3) Risk assessment conclusion
Based on the above analysis, the risks of technology realization and business development of this project are relatively small, and the risks can be reduced to a minimum.

4.2.3 Economic benefits

After the complete system reformation, the water lubrication system is as safe and stable as the oil lubrication system. The service life is also comparable to the oil lubrication system, even longer. It saves the cost of shipowner docking and saves metal parts and forever solved the problem of fines for environmental issues.

4.2.4 Social benefits

According to a maritime administrative department of a county-level city in the Yangtze River region of China, from January 2010 to April 2011, the navigation mark maintenance work vessels "Yu Dao Biao 303" and "Yu Dao Biao 304" belonging to this department had three consecutive sudden oil leakage due to sealing failure caused by fishing net winding during normal cruising. The "Hunxun 304" boat, which was compiled by the department in January 2012, has experienced two sudden oil leaks
due to seal failure due to fishing net winding in less than one year.

It can be seen from this that if the stern shaft oil leakage event is counted, the data on the number of oil spilled ships and the number of leakage will be quite alarming. The implementation of the lubrication system replacement of small and medium-sized ships as soon as possible is conducive to improving the pollution of rivers and marine environments, heightening the quality of life of inland residents along the river and the quality of life of coastal residents.
5.1 Case Analysis of Oil-to-Water Reform of China Shipbuilding Heavy Industry
Shanhaiguan Shipyard (2006)

This paper selects a typical oil-to-water case from a Chinese shipyard in 2006 as an analysis. The shipyard is a Shanhaiguan shipbuilding and shipyard affiliated to China Shipbuilding Industry Corporation. The 23-year-old 76000DWT single-hull tanker CABOT MONROVIA has been transformed into a bulk carrier. Among them, the tail pipe system was changed from an oil lubrication system to a water lubrication system. After the conversion, the ship was renamed CSL ACADIAN. In this case, the water-lubricated bearing Compac system of Canadian Dragon Company was selected.

Figure9- CABOT MONROVIA and CSL ACADIAN.
Source: www.thordonbearings.com

Thordon has accumulated experience in seawater lubricated propeller shaft bearings in many navy and coast guards worldwide. For safety reasons and non-catastrophic failure modes, the navy and coast guards almost always use seawater as propeller shaft bearings. However, today, more and more commercial ship owners are seeing the reliability of this polymer bearing. Thordon's seawater lubricated propeller shaft bearing system has been put into use on more than 2,000 ships, eliminating the risk of oil leakage from the stern seals, providing excellent operation and bearing wear performance, and reducing utilization costs.

The idea of this case is to use seawater instead of oil for lubrication, and non-metal Thordon COMPAC bearings instead of white metal bearings. The seawater is taken
from the sea, pumped into and returned to the sea through bearings. The use of Thordon seawater lubricated bearings can eliminate the potential impact of stern tube oil seals, as well as oil storage, sampling and disposal of stern tube oil pollution. However, a major difference is that the propeller shaft and stern tube require corrosion protection against seawater. Bronze bushings are recommended, so corrosion protection may mean higher upfront costs for for-tube bearing systems. However, due to the elimination of the stern seal and related maintenance, the upfront cost can be compensated with a lower service cost, without having to worry about the damage of the stern seal, or paying high pollution fines and bad publicity.

5.2 What the Thordon Compac system contains

• An assessment of original bearing loading condition
• Conversion design package and work schedule
• Thordon COMPAC seawater lubricated (orange) bearings
• Bronze shaft liners
• Thor-Coat shaft coating
• Water lubricated forward seal
• Thordon Water Quality Package

5.3 Strategies for minimizing conversion costs

• Conduct engineering up front to anticipate problems
• Utilize standard designs
• Firm quotes for work
• Tie conversion into tailshaft survey cycle
• Plan ahead with plenty of time in advance
5.4 Review of ship parameters before conversion

Before considering a Thordon COMPAC conversion, Thordon Bearings will require specific information from the ship to determine if the ship can be converted. Thordon will review the following:
1) that space is available for fitting of shaft liners to Classification Society required thickness
2) that bearing loads are acceptable to Classification Society limits for water lubricated bearings
3) to determine bearing offsets and machining such as required etc. to maintain the existing shaft centerline alignment.

Once these topics are reviewed and deemed achievable, Thordon will advise if the conversion is possible. A typical COMPAC conversion will involve the following 12 step process

STEP 1. Engineering and suitability review
STEP 2. Drain Oil, remove shafts, clean and verify dimensions

![Figure 10](www.thordonbearings.com)

STEP 3. Machine shaft liner ID
STEP 4. Heat liners (as required) for interference fit on shaft

Figure 10 - Drain Oil, remove shafts, clean and verify dimensions
Source: www.thordonbearings.com

STEP 5. Fit liners on shaft
STEP 6. Remote old bearings
STEP 7. Heat new bearings
STEP 8. Machine new bearings
STEP 9. Fit new bearings
STEP 10. Fit new shafts
STEP 11. Fit new stern tube
STEP 12. Fit new shafts and stern tube

Once these steps are completed, the ship will be ready for operation with the new Thordon COMPAC system.
STEP 5. Machine OD of shaft liners to correct size and finish

STEP 6. Shaft preparation and application of Thor-Coat shaft coating

STEP 7. If bearing carriers are required, correctly position carriers and install

STEP 8. Machining Polymer bearings

STEP 9. Interference fitting of COMPAC bearings via freezing

STEP 10. Refit propeller shaft

STEP 11. Fit seal and confirm seal integrity

STEP 12. Supply clean water to bearings with a Thordon Water Quality Package

Many of China Shipping Oilfield Services Co., Ltd.'s PSV work vessels have been changed to water lubrication. Because these ships serve offshore oil fields, the oil leakage problem is more sensitive, and maintenance is more troublesome. There is much sediment in the shallow water environment, and oil lubrication is also prone to problems. The economic loss caused by the shutdown is very large. After changing to water lubrication, there will be no more pollution problems, and the maintenance time
will be very short. Basically, it is to replace the bearing bush. Of course, water-lubricated bearing manufacturers and distributors have done some technical and customer relations work. The bearing pressure of the boat is not high, and usually does not require a matching stern tube water treatment device, and the full sink design. Of course, the effect of supporting water treatment is better, because the water quality is purified, but the investment will be 200,000-300,000 yuan more.
CHAPTER 6 Conclusion

This paper discusses the feasibility of transforming the ship's stern shaft system into a water lubrication system based on the pollution caused by oil pollution to the ocean. And then discussed two solutions to solve the problem of water lubrication: one is to add a water treatment device for the open water lubrication system, and the other is to replace the oil into water directly by improving the equipment in the system on the basis of oil lubrication.

The ship's stern tube bearing is one of the key components of the ship's propulsion system, which is directly related to many aspects such as the safety, comfort and economy of the ship's navigation. The stern tube bearing material directly determines the performance of the stern bearing, so the research on the material of the stern bearing of the ship is of great significance. This paper introduces several types of water lubricated bearings, including: wood materials, metal materials, ceramics, rubber materials, engineering plastic materials (nylon and ultra-high molecular weight polyethylene), modified composite materials. Modified composite materials are obtained through the mixing of two or more substances, and the advantages of various properties of the two materials are selected to improve the comprehensive properties of the materials. This paper also introduces methods of modifying materials: polymer blending modification, fiber reinforced modification, solid lubricant filling modification, nano material modification, multi-element composite modification.

The selection of multi-element composite modified materials is the first choice to improve the stability of water lubricated bearings, considering the rotation speed and pressure factors and the material and roughness of the dual parts.

Combining the selection and improvement of water lubrication materials and the theoretical basis of water lubrication mechanism, this paper analyzes the cost and
specific cases of transforming the oil lubrication system into a water lubrication system. In summary, the large-scale promotion of water lubrication systems is technically feasible, economically advantageous, and has high social value and environmental protection value.
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